Investigation of bubble interaction with gas-liquid and liquid-liquid interface

Abstract

Bubble dynamics plays a crucial role in a wide range of chemical process industries, where understanding bubble formation, behaviour in different fluid environments, and interaction with interfaces is vital for optimizing reactor performance, enhancing mixing efficiency, and improving overall production rates. This dissertation systematically investigates the interaction of bubbles with gas-liquid and liquid-liquid interfaces and is presented in four comprehensive parts. In the first part, the study revisits the fundamental problem of bubble formation in liquids of extreme viscosities, addressing discrepancies in the literature. Bubbles were generated using needles of diameters ranging from 0.84 mm to 1.54 mm at gas flow rates between 5 ml/min and 80 ml/min. The experiments reveal distinct behaviours in low-viscosity fluids (e.g., deionized water), where bubble necking time remains nearly constant with gas flow rate, and daughter bubbles emerge due to secondary necking. In contrast, in high-viscosity fluids (e.g., glycerol), smaller bubbles were observed to slide over larger ones and coalesce symmetrically along the axis. The interaction point (whether at an angle or inline interaction) between the bubbles plays an important role in determining whether bubbles coalesce or slide past each other. Additionally, a new observation of bubble pairing (doublet formation) is reported at low gas flow rates with larger needle diameters. The second part focuses on the dynamics of bubble bursting at the gas-liquid interface, extending from bubble formation to satellite droplet ejection. The influence of surfactant concentration (ranging from below to above the critical micelle concentration, CMC) and non-dimensional liquid height (h/D) is explored. Experiments are conducted with a fixed needle diameter of 1.36 mm in different surfactant concentrations. The study shows that the bubble size is largest in clean water and decreases with surfactant concentration. In the presence of high surfactant concentrations, the aspect ratio of the bubble ranges from 1 to 1.5, and crater formation after bursting becomes less pronounced. Surfactants delay both the time required for a bubble to reach the interface and the bursting time of the bubble. At high concentrations, satellite droplet ejection is suppressed entirely. Interestingly, satellite droplet size and height exhibit monotonic trends with surfactant concentration and non-monotonic trends with h/D, whereas crater depth is influenced by bubble size, film thickness, and surface tension. The third part of the research focuses on bubble interactions with thin and thick liquid-liquid interfaces with relevance to oil-spill mitigation. The viscosity of the upper (oil) layer is varied from 0.65 to 1000 cSt, while the lower phase (bulk) is water under surfactant-free and surfactant-laden conditions. For thin interfaces(1 mm), we focus on bubble bursting at the interface, including cavity collapse and the formation of a satellite droplet. The formation of oil droplets in the bulk is studied for both single-bubble and bubbly-flow interactions with the liquid-liquid interface, in the presence and absence of surfactant. After the system reaches a steady state, DLS measurements are performed on samples at 1 h and 24 h to examine the size and stability of the oil-in-water emulsion. The present study is also extended to a thick upper layer (4 cm), where all possible outcomes of bubble collisions with the liquid-liquid interface are observed, including bubble trapping at the interface, water jet piercing into the bubble after jet entrainment, and jet breakup into single or multiple droplets. An attempt has been made to summarize these outcomes using a regime map based on bond number and retention time. Overall, this dissertation provides new insights for understanding bubble-interface interactions in complex fluid systems, contributing to the development of more efficient and controlled processes in industrial applications involving multiphase flows.